Ignite: Place-based Community-centered Design to Promote Biomedical Engineering Efficacy

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Abstract

This study evaluates the impact of Ignite's Health programming, an informal engineering experience designed for middle and high school students and facilitated by Duke University undergraduate students. Participants design health-related projects such as pulse oximeters while gaining hands-on experience in problem-solving and the engineering design process. Ignite's Health program is guided by constructivist and resilience theories and seeks to empower secondary-aged students to grow their skill sets in biomedical engineering and encourage them to pursue science-oriented careers in the future. Constructivist theory emphasizes the active role that students play in the learning process by drawing upon their past experiences to generate new knowledge. Resilience theory focuses on facilitating students' ability to adapt to and navigate setbacks.

Data was collected from surveys and interviews conducted during three middle and three high school implementations between 2021 and 2024. An analysis of the data revealed that Ignite Health participants experienced increased confidence in their STEM abilities, stronger self-perceived identities as engineers, and higher levels of resilience, especially among female and gender minority students. These results suggest that Ignite is effective in building self-efficacy and increased engagement in STEM, particularly for underrepresented groups, and may lead to increased student interest in pursuing science- and engineering-related careers in the future.

Introduction

Quality education has been shown to be key to improving lives and advancing society [1]. Yet, equitable education remains a challenge worldwide, particularly among school-aged girls in science, technology, engineering, and mathematics (STEM) [2]. Although the demand for biomedical professionals is increasing, many K-12 students in the United States are falling behind in science and math, leaving them less prepared to pursue STEM job opportunities in their communities [3, 4]. This gap is particularly pronounced in the engineering field, evident by women making up 50% of all STEM jobs but only 15% of engineering positions [5].

The Duke University Center for Global Women's Health Technologies (GWHT) created a sustainable educational program called Ignite in 2014 to address a lack of access to quality K-12 engineering education and empower secondary school-aged students to explore engineering design concepts. Ignite started as an international program, partnering with secondary-aged students in Kenya and India to solve key issues related to light and energy and with school-aged children in Guatemala to address local water challenges. During the COVID-19 pandemic, we introduced an additional Health-specific curriculum based on community partners' desires for fact-based examples of healthcare. In 2020 Ignite also shifted its focus to meeting the needs of the local Durham community. Through a partnership between Duke's Department of Biomedical Engineering and the Museum of Life and Science (MLS) in Durham, North Carolina, Ignite shifted its goal to help equip local students with the tools they need to solve challenges related to health in their community.

Ignite utilizes a near-peer teaching model, pairing undergraduate students ("Trainers") with local middle and high school students ("Learners" and "Makers", respectively) to guide them through an engineering design project. These projects address local concerns related to the United Nations (UN) Sustainable Development Goal (SDG) 3: Good Health and Well-being in the context of biomedical engineering (BME) [6]. Guided by project-based learning (PjBL), students work on projects rooted in local, community-based health problems using the human-centered design process.

The Ignite Learner program takes place over the course of eight weeks each spring. Weekly sessions alternate between 2-hour in-person sessions at the MLS and 1-hour virtual sessions via Zoom. Participants are asked to complete the pre-survey questionnaire before the start of the first session. Each of the following weekly sessions, facilitated by undergraduate Trainers, focus on a different concept related to the engineering design process. These sessions are as follows: needs finding, skills building, brainstorming, building, iterating, finalizing, and presenting.

The Makers course for high school students spans the entire academic year (September-April), with meetings and building sessions taking place on a weekly basis. Makers are asked to complete the pre-survey before the start of the program in the fall. Meetings for the Maker program typically last one hour and are less rigid, allowing Makers the opportunity to share updates with their classmates and receive feedback from the Trainers during these times.

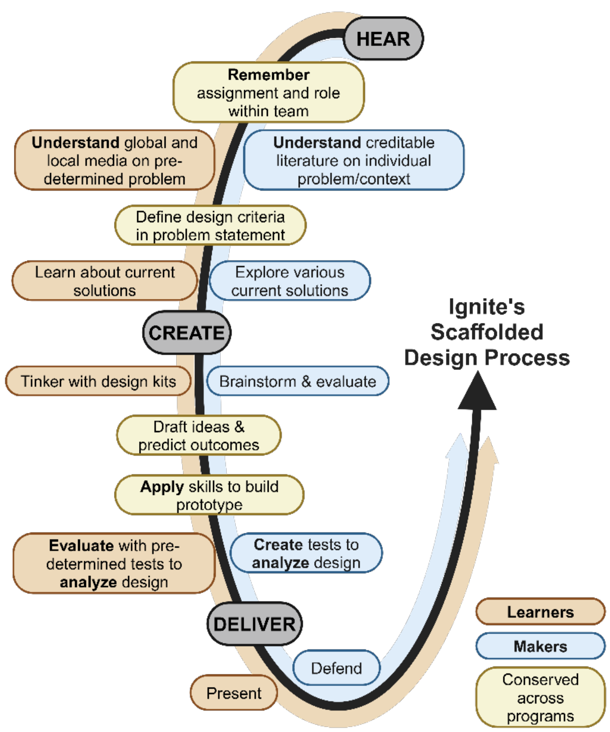

Figure 1. Scaffolded, differentiated course design for Ignite's middle school (Learners) and high school (Makers) programs. Figure created in https://BioRender.com

Both Learners and Makers present their projects to Duke and MLS staff in addition to their family members on the same day during Ignite's annual design day symposium in the spring. At the conclusion of the program, students complete the post-survey questionnaire.

Both the Learners and Makers courses follow a parallel scaffolded design process, where students are methodically introduced to various aspects of the engineering design process (**Figure 1**). Undergraduate Trainers across the Pratt School of Engineering and Trinity College of Arts & Sciences with an interest in education and/or community engagement are interviewed, selected, and trained to facilitate this process. First, trainers help participants empathize with challenges faced by those in their community by having students learn about local needs according to community reports, followed by researching current solutions and their limitations. Next, participants ideate or brainstorm possible solutions through open inquiry. Prototypes undergo testing methods to determine if the solutions meet the design specifications. Finally, participants participate in a Design Day symposium where middle school students present research posters and high school students present oral presentations to their families, other students, guests, and a panel of professionals, including Museum and Duke University faculty and staff.

In the Learners course, the design process is more structured, with the problem space confined to learning about heart and lung diseases in the community and all Learners, in return, designing low-cost, Arduino-based pulse oximeters (**Figure 2A**). Meanwhile, the high school program, Makers, has a small, individualized mentorship model where undergraduates are matched to high school students who source their own projects. In the past, these projects have included a bike-appropriate attachment for chemo-induced pediatric neuropathy, a custom knee brace for osteoarthritis, and a portable second-hand smoke detector (**Figure 2B-D)**.

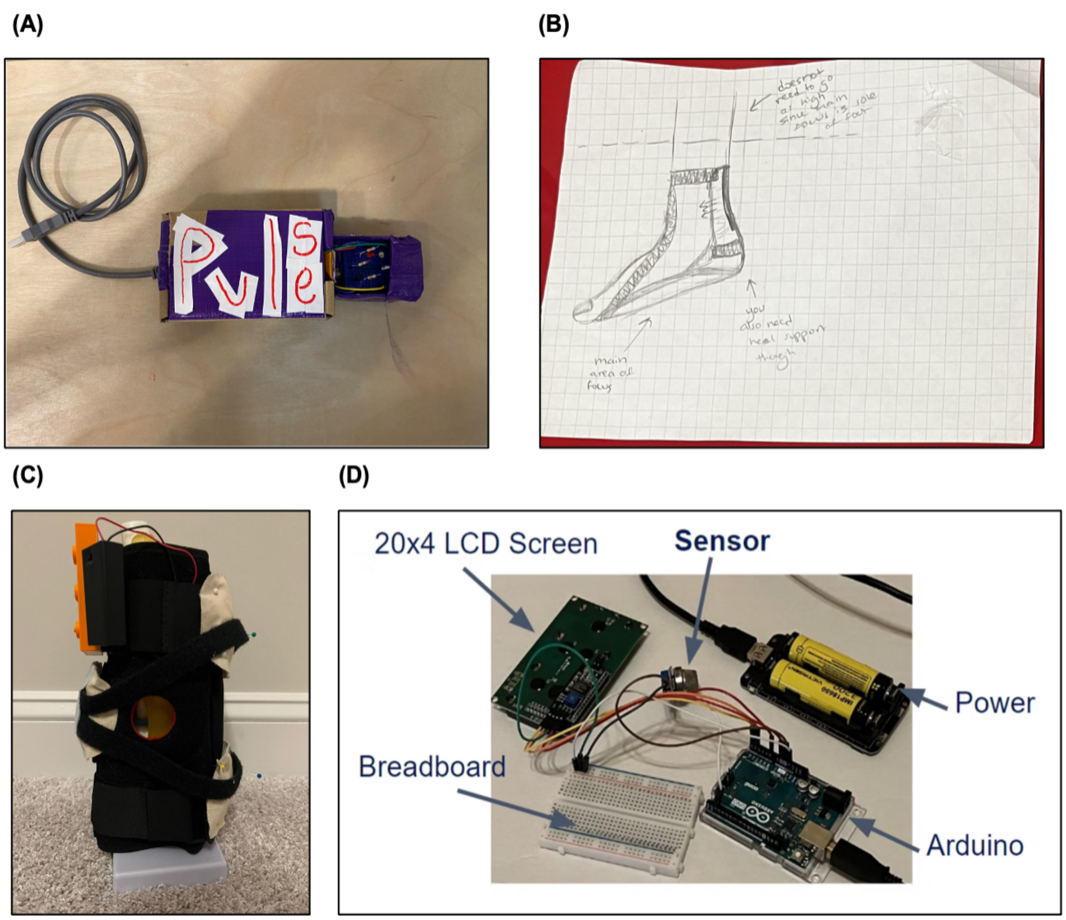

Figure 2. (A) Example of an Arduino-based pulse oximeter designed by an Ignite Learner. Ignite Maker projects (B) sketch of a custom bike attachment for chemo-induced neuropathy and (C) ThermoChill knee brace and (D) physical prototype of second-hand smoke detector.

The ultimate aim of both of our programs is to cultivate the next generation of innovators by offering hands-on biomedical engineering opportunities to humanize problem-solving, build resilience, and bolster a student's ties to their community.

Literature Review

Constructivist Theory

According to constructivist theory, learning is a largely student-centered process, where students lead the discovery process and teachers serve in a supportive role [7]. This allows students to play an active role in the learning process, drawing upon their past experiences to shape their learning and reach new conclusions [7]. In the context of Ignite Health, students are encouraged to use their past experiences to help define a problem in their community, brainstorm solutions, and create a design that is suited to that context. Rather than prescribing specific solutions, the application of constructivist theory shows students that their learned experiences are valuable in shaping their projects.

Resilience Theory

Resilience theory emphasizes the important role that resilience has in helping students meet the challenges and rigor that a career in STEM necessarily requires [8]. Grit, a concept closely interlinked with resilience theory, has been shown to play an important role in enabling students to pursue challenging tasks, self-regulate, and maintain objectivity when encountering stressful situations [9]. Ignite aims to support students in developing and/or honing their ability to navigate setbacks, cultivate grit, and realize that they can adapt to challenges. This is purposely structured within both programs where iteration is a necessary step, reducing the barriers or fears surrounding failure by requiring students to test and alter designs throughout the program. While this challenges students, often for the first time in their education, with a problem without a defined solution, we aim to cultivate a safe place for students to experiment, tinker, and adapt.

Connection to the Ignite Program

Our program draws on both the constructivist and resilience theories to increase students' attitudes toward STEM, resilience, and confidence. By working through the engineering design process, we aim to showcase to students the value of taking ownership of their own learning process and developing the resilience/grit needed to solve real-world problems relevant to their community related to biomedical engineering.

Female Involvement in STEM

Although STEM education has been recognized as playing an important role in developing the next generation of innovators and problem-solvers, there continues to be a gender gap in the field. Recent research suggests that females tend to pursue advanced STEM courses and careers at a lower rate than their male counterparts, primarily due to redirecting their attention towards other fields because of a lack of encouragement from their parents, teachers, and peers [10]. It is important to point out that this in way plays into students' intrinsic motivations. According to the American Association of University Women (AAUW), ensuring that women have equal opportunities to engage in and succeed in STEM-related activities not only narrows the gender pay gap but also strengthens economic security for women and families while simultaneously diversifying the STEM workforce [11]. Informal educational programs like Ignite have proven successful in recruiting and supporting female and gender minority students in STEM [12]. Our program has historically recruited a large number of female participants, and we aim to create an environment that helps to address the underrepresentation of women in STEM and empower participants to pursue higher education and careers in these fields.

Previous studies have used the constructivist approach to improve female student involvement in STEM education. For example, Kijima et. al. used the constructivist theory to engender creative confidence, empathy, and global competence among female youths between the ages of 13 and 18 through a three-day design-thinking workshop. Utilizing STEM and STEAM approaches, the latter of which incorporates Arts into its framework, this workshop aimed to allow young female students to identify and address a real-life problem in a collaborative, social setting, and was found to have built collaboration and communication skills, as well as increase students' creative confidence and interest in engineering [13].

Similarly, de Melo Berezza et. al. developed a framework to spark young females' interest in STEM. This program was led by female undergraduate students who were tasked with creating the curriculum and lecture materials to present to the young students. The lectures were also followed by three-hour workshop sessions that allowed the students to gain hands-on experience and apply the knowledge that they learned in the lectures. The workshops in particular were found to spark students' interest in STEM and pursuing a STEM-related career, while the lectures sparked interest in STEM-related projects. This framework – by allowing female undergrads to lead – helped to engage both the undergrads and students in STEM [14].

Although existing literature has explored the role that STEM programs have in cultivating resilience amongst students, few have applied resilience theory to educational research in STEM [15]. Given the demanding nature of a career in STEM and the important role that resilience plays in prolonged STEM engagement, future studies should address this gap in the literature by evaluating STEM learning environments using a resilience theoretical lens [8].

Methodology

We assessed the impact of our program on Learners (n=53), Makers (n=22), and Trainers (n=21) participating in Ignite's Health curriculum using survey and interview data collected from 2021 to 2024. Middle and high school participants were predominantly recruited from public schools. Participants were diverse in race and ethnicity, 27% as Black, 21% as White, 45% as Asian, and 7% as Other with 5% identifying as Hispanic, Latino, or Spanish origin. Female and underrepresented gender groups made up a majority of students in each group, with 64% of Learners, 82% of Makers, and 91% of Trainers identifying as female or underrepresented gender groups.

The focus of our study was twofold: (1) Evaluating self-efficacy and (2) Examining identity formation resulting from participation in Ignite. Metrics surrounding these two categories were chosen as these scores have been shown to significantly impact students' educational and career trajectories [16], [17] while being cognizant of survey fatigue in our students. Specifically, we chose to measure students' attitudes toward STEM, math, science, and engineering, as well as levels of self-reported resilience, before and after participation in Ignite using previously validated metrics (see **Table 1**) [18], [19], [20], [21]. All questions utilized the Likert Scale, enabling students to select responses ranging from strongly disagree (1) to strongly agree (5). This allowed the research team to quantitatively analyze Ignite's effect on these two categories.

	Statements	**Citation**
STEM Attitudes	My STEM education will help me get a good job.	Faber et al. [18]
	STEM can help me engineer (tinker/build) useful things for my community.	Faber et al. [18]
	In the future, I would consider getting involved in more STEM opportunities.	Faber et al. [18]
Math Attitudes	I feel confident about my abilities in math.	Faber et al. [18]
	I would like the opportunity to take more math courses.	Faber et al. [18]
	I would consider a career related to math.	Faber et al. [18]
Science Attitudes	I can use science to help people and make a difference in my community (family/friends/neighbors).	N/A
	I feel confident about my abilities in science.	Faber et al. [18]
	I would like the opportunity to take more science courses.	Faber et al. [18]
	I would consider a career related to science.	Faber et al. [18]
Engineering Attitudes	I feel confident in my abilities to engineer (tinker/build).	Faber et al. [18]
	I would like the opportunity to take more engineering courses (tinker/built).	Godwin [21]
	I can use design thinking to solve problems.	Faber et al. [18]
Resilience/Grit	I can help solve meaningful real-world problems using STEM.	Faber et al. [18]
	I am motivated to solve problems that I think help my community and the world.	Dotson et al. [19]
	I have overcome setbacks to conquer important design challenges.	Duckworth and Quinn [20]

Table 1. Summary of components contributing to students' average STEM attitudes, science, math, engineering, and grit scores, based on previously validated metrics.

For Makers and Trainers specifically, a known, validated metric of engineering design was also utilized to assess student confidence, motivation, and anxiety related to the engineering design process (**Table 2)** [22]. Due to the older age of students completing this metric, this survey was used in its entirety. Students were asked to rate their degree of confidence, motivation, and anxiety, respectively, to perform each of the following tasks, rating their answers on a scale of 0-100 (0, 10, 20, 30 etc. where 0=cannot do it at all, 50=moderately can do, and 100=highly certain can do):

Categories	Confidence Motivation Anxiety
Statements	Conduct engineering design Identify a design need within the community Research a design need Develop design solutions Select the best possible design Construct a prototype Evaluate and test a design Communicate a design Redesign/iterate

Table 2. Statements used to assess confidence, motivation, and anxiety around engineering design for Ignite's Makers and Trainers, derived from Carberry (2010).

All analyses were performed in JMP, comparing pre- and post-surveys with paired t-tests. Statistical significance was determined as less than 0.05, with one star (*) indicating a p-value less than 0.05, two stars (**) representing p-values less than 0.01, and three stars (***) for p-values less than 0.001. This study was conducted in accordance with Duke University IRB-approved protocol number 0087.

Results and Discussion

Science Attitudes

After completing the program, both Learners and Makers reported a significant increase in their attitudes toward science (p=0.0005, n=56) as shown in **Figure 3A**. A breakdown of changes in students' average science attitude scores by statement is provided in **Figure 3B**, showing that there was an overall increase in students' accordance with using science to help people and make a difference in their community, having confidence about their abilities in science, and considering pursuing a career that is related to science.

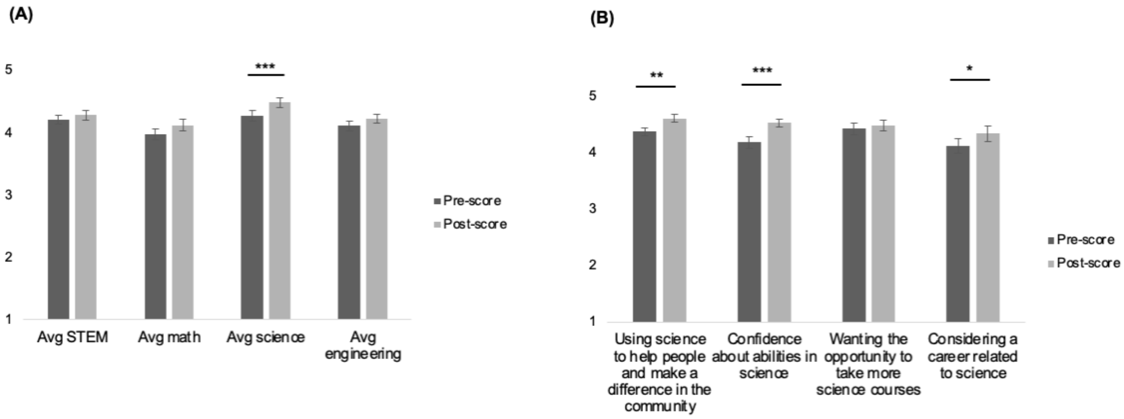

Figure 3. (A) Average scores for STEM, math, science, and engineering categories among Learners and Makers before and after participation in Ignite (n=56). Avg = average. Statistical analysis was performed using a paired t-test. Error bars represent standard error of the mean (SEM). (B) Average science scores by statement among Learners and Makers before and after participation in Ignite. Bars represent the mean ratings for each statement, with sample sizes as follows: Statement 1 (n=56), Statement 2 (n=55), Statement 3 (n=56), and Statement 4 (n=56). Statistical analysis was performed using a paired t-test for each statement. Error bars represent standard error of the mean (SEM) for each statement.

Interviews with participants affirmed how students' perceptions toward science changed as a result of their involvement in Ignite. At the conclusion of our program, when asked about how their college and career goals or research interests may have changed since starting the Ignite Maker Program, a female student in the 2022-2023 cohort who was interviewed said: "They have slightly changed … At first, I wanted to go down more of a humanities track [in global health] … Now I feel as though I might want to take a more science-oriented direction." This student's experience with Ignite demonstrates how involvement in our programming can help broaden students' perspectives, encouraging them to explore new fields and develop stronger interests in pursuing a science-oriented career in the future.

Resilience

We saw that Learners and Makers who participated in Ignite experienced a significant increase in their self-reported levels of average grit/resilience after completion of the program ($p=0.016$, $n=56$). Specifically, we observed a significant improvement in students' perceived ability to overcome setbacks in solving important design challenges (**Figure 4**).

For Learners and Makers alike, Ignite served as their first time building a prototype without a closed-in solution, which required significant resilience. Participants had to learn how to troubleshoot and iterate on their initial designs based on testing, making modifications to their projects along the way. High school participants, who were tasked with identifying and creating a solution for a health-related problem that they would like to solve on their own, faced additional challenges. This process requires Makers to distill a big idea into a manageable project and then iterate upon that idea to a single needs statement. This kind of problem-solving is something that is typically expected at the graduate level, making it a unique opportunity for high schoolers to problem-solve and tackle different challenges that arise during the engineering design process.

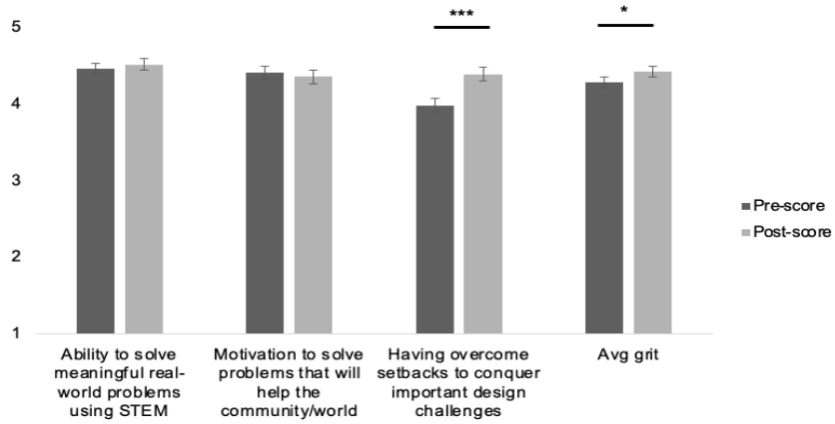

Figure 4. Average grit scores by statement among Ignite's Learners and Makers before and after participation in Ignite (n=56). Avg = average. Statistical analysis was performed using a paired t-test. Error bars represent standard error of the mean (SEM).

Engineering Abilities

Although there was not a statistically significant increase in students' overall average engineering scores, there was a marked increase in students' confidence in their abilities to engineer (tinker/build) after completion of the program (**Figure 5**). The finding highlights the potential for programs like Ignite to positively influence students' confidence related to engineering, tinkering, and building, which may, over time, contribute to stronger engineering identities amongst participants in the program.

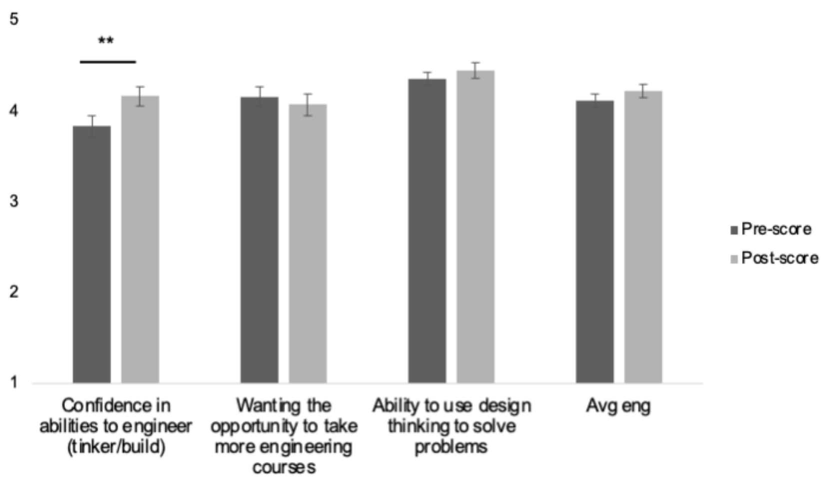

Figure 5. Average engineering identity scores by statement among Ignite's Learners and Makers before and after participation in Ignite. Bars represent the mean ratings for each statement, with sample sizes as follows: Statement 1 (n=55), Statement 2 (n=56), Statement 3 (n=56), and Avg (n=56). Avg = average. Statistical analysis was performed using a paired t-test. Error bars represent standard error of the mean (SEM).

Scores Among Female and Gender Minority Participants

Among female and gender minority middle school and high school participants in particular (n=39), we saw that average science, grit, and engineering identity scores all increased. **Figure 6A** shows the overall average scores for each category, while Figures **6B-D** provide detailed results for individual statements under the science, grit, and engineering categories, respectively.

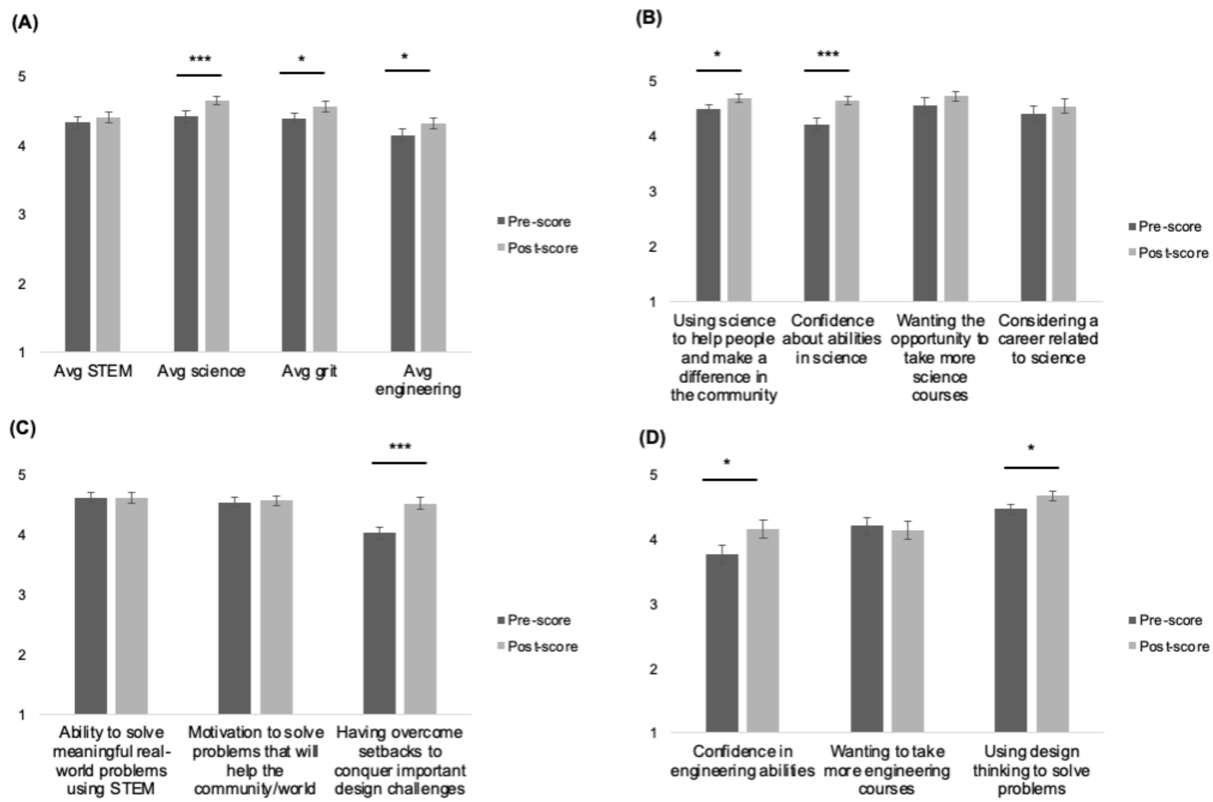

Figure 6. (A) Females and gender minorities' average scores for STEM, science, grit, and engineering categories before and after participation in Ignite (n=39). Avg = average. Statistical analysis was performed using a paired t-test. Error bars represent standard error of the mean (SEM). (B) Females and gender minorities' average science scores by statement before and after participation in Ignite (n=39). Statistical analysis was performed using a paired t-test for each statement. Error bars represent standard error of the mean (SEM). (C) Females and gender minorities' average grit scores by statement before and after participation in Ignite (n=39). Statistical analysis was performed using a paired t-test for each statement. Error bars represent standard error of the mean (SEM). (D) Changes in females and gender minorities' self-perceived identities as engineers by statement before and after participation in Ignite. Bars represent the mean ratings for each statement, with sample sizes as follows: Statement 1 (n=38), Statement 2 (n=39), and Statement 3 (n=39). Statistical analysis was performed using a paired t-test for each statement. Error bars represent standard error of the mean (SEM).

These results suggest that Ignite was particularly impactful for female and gender minorities participants across the board, especially in terms of improving attitudes and confidence toward science and engineering, building confidence in overcoming design challenges, and using the engineering design process as a framework for problem-solving. Although there was no statistical significance in this population wanting to take more engineering courses, these findings demonstrate the importance of informal experiences in engineering in increasing female and gender minorities' confidence and encouraging design thinking when problem-solving.

Scores Among High School Participants and Trainers

To assess the impact of Ignite on both participants' and mentors' perceptions toward the engineering design process as they work together toward a solution, we included additional metrics for Ignite's Makers and Trainers.

When measuring confidence, motivation, and anxiety surrounding the engineering design process, Makers and undergraduate Trainers report a significant increase in confidence across all participants (**Table 3**). A breakdown of confidence scores by statement for all students is provided in **Figure 7A**, and this observation is conserved in female and gender minority participants in **Figure 7B**, demonstrating that students experienced the greatest increases in their confidence related to conducting, identifying, developing, selecting, and constructing a design.

	Females (n=35)		**Males (n=6)**		**Overall (n=41)**	
	Difference	P-value	Difference	P-value	Difference	P-value
Confidence	7.03	**0.0092**	3.89	**0.047**	6.03	**0.0032**
Motivation	1.46	0.4146	-4.07	0.5614	0.63	0.7259
Anxiety	-0.62	0.8741	-5.74	0.7633	-1.37	0.7409

Table 3. Summary of mean differences in confidence, motivation, and anxiety in engineering design between Makers and Trainers, broken down by gender (male, female) and overall. Note: For females, the overall sample size is n=35, but for confidence and motivation, the sample sizes are n=34. For the overall group, n=41 for the full analysis, with n=40 for confidence and motivation.

During a semi-structured interview following the end of Ignite, a 2022-2023 Maker expressed how Ignite provided her with a framework to implement solutions that will help improve health outcomes in her community. She said, "I really want to be able to help move closer to attaining this goal, and I think that through Ignite, I began to understand more what methods of helping are actually beneficial." This shows that Ignite provided them with tangible skills that could be applied to improving health/the biomedical engineering process.

Interview data also revealed that involvement in Ignite facilitated a new type of thinking among students. When speaking with a 2021-2022 Maker, they said "The best part of Ignite was definitely the ability to come up with something completely from scratch while still having the insight from so many people working on the same projects. The freedom to create anything and everything is what inspired me to think outside of the box." This shows that, through Ignite and by leveraging a constructivist theory framework, students are able to shape their own learning and gain confidence in their creativity, problem-solving skills, and engineering design abilities.

Trainers also received benefits from participating in Ignite. As one senior undergraduate Trainer in the 2021-2022 Ignite program majoring in biomedical engineering shared, "[Ignite] has reinforced the importance of biomedical engineering to me personally and also shown me just how much variety there is in biomedical engineering." This reflects how even senior undergraduate students with multiple years of experience of BME coursework have been able to solidify their interests across BME by participating in curricula development as well as serving as mentors to younger students, providing hands-on support across a range of projects.

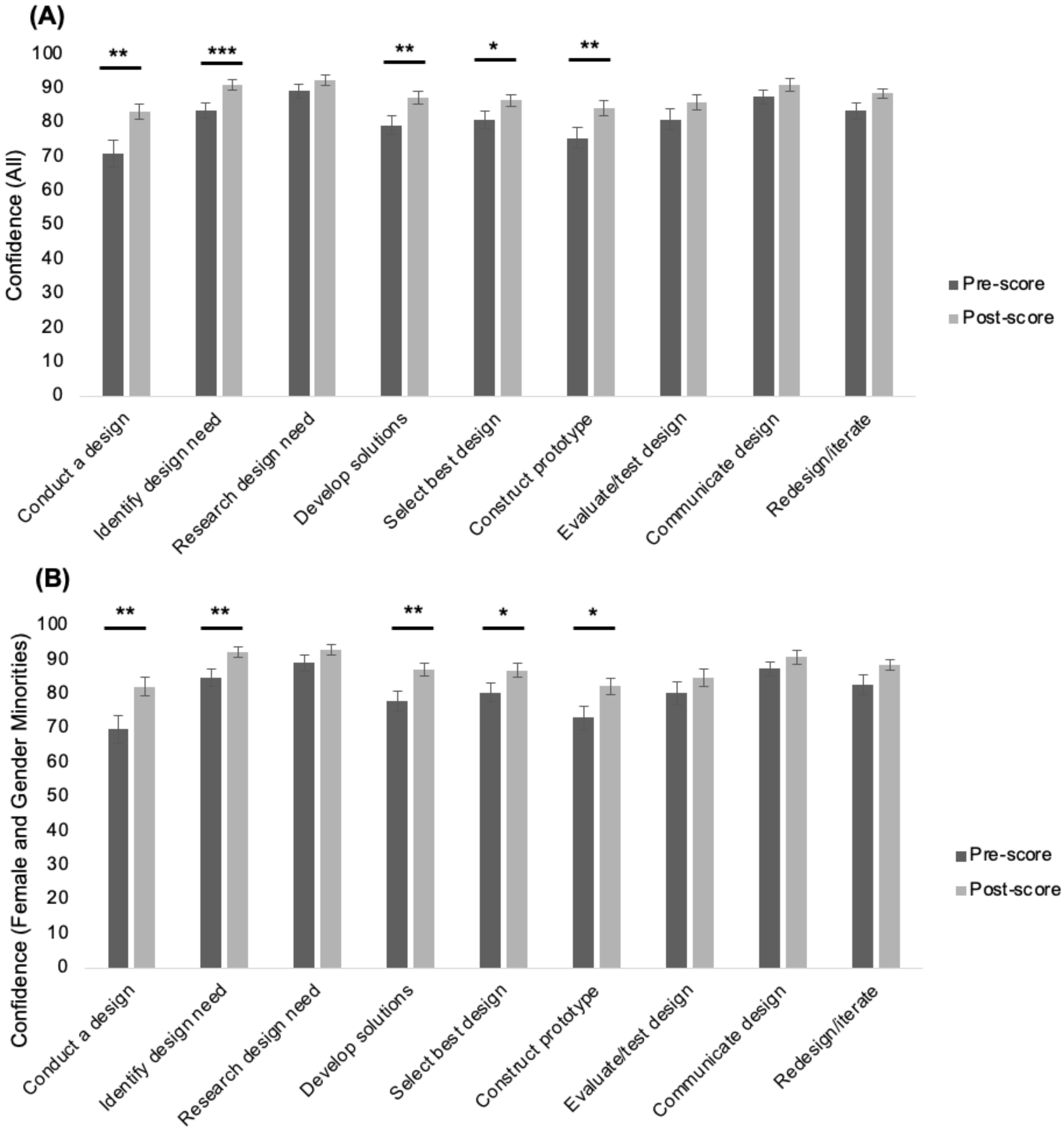

Figure 7. (A) Graph illustrating students' confidence levels across different steps of the engineering design process (n=41 for all steps except 'select best design' and 'construct prototype', where n=40). Statistical analysis was performed using a paired t-test for each statement. Error bars represent standard error of the mean (SEM). (B) Graph illustrating female and gender minority students' confidence levels across different steps of the engineering design process (n=35 for all steps except 'select best design' and 'construct prototype', where n=34). Statistical analysis was performed using a paired t-test for each statement. Error bars represent standard error of the mean (SEM).

Future Directions in Program Development

As Ignite begins its fourth year running in our local community in 2024, we are currently starting to implement engagement metrics throughout the duration of Ignite to give a more robust picture of student development across the program. By introducing these metrics, we aim to better account for any external factors that may be affecting students' scores, such as students becoming more confident in their abilities as a result of their formal schooling experiences that occur during their time with Ignite. Since we are collecting data on real individuals with lives beyond Ignite, it can be challenging to separate the effects of these external influences from the program's impact, and we hope that by collecting data throughout the program, we can more accurately discern the effects of Ignite in particular. In addition, a more consistent evaluation of Ignite's programming may help to minimize response-shift bias, a phenomenon in which students may report misleading differences in perceived self-efficacy at the pre- and post-stages due to changes in their understanding of the construct over time [23]. In addition, we have expanded the pre- and post-survey questionnaires to include additional questions related to resilience/grit from the short grit scale [20]. We hope that this will allow us to more robustly test this metric in further iterations of Ignite.

Lastly, Ignite has broadened its reach through a pilot, Ignite Entrepreneurs, designed for high school students to continue their Ignite Makers project within the context of Entrepreneurship so that high school students experience the contextualization of engineering within the field of scaling, IP, marketing, and sustainability.

Limitations

To reduce the burden of long surveys on students, we chose to abbreviate the pre- and post-survey questionnaires for Ignite Health's middle school participants. This included consolidating pre-existing metrics that assessed participants' self-efficacy and identity formation in STEM, engineering, and resilience/grit. While these instruments had not been tested together previously, which may decrease the validity of our survey, we opted to maintain these established metrics in order to consistently track and compare Ignite's results year over year. Similarly, it is important to note that Ignite did show significant improvements to students' confidence surrounding engineering design using the full metric for efficacy among high school participants and undergraduate Trainers.

Conclusion

The results of our study suggest that the Ignite Health program was effective for Learners, Makers, and Trainers alike in increasing excitement and confidence around STEM, strengthening students' engineering identities, and improving self-reported levels of resilience and grit. Specifically, we found that female and gender minority students between the ages of 11 and 18 were particularly able to benefit from Ignite's programming, experiencing significant increases in their average science, grit, and engineering scores before and after participating in Ignite. Although female and gender minority participants expressed no increased desire to take more engineering courses, we did see an increase in their confidence around engineering and in their likelihood to use design thinking to solve problems. This increase in confidence despite not wanting to take more courses may seem contradictory at first. However, it also may suggest that informal engineering educational experiences, such as those provided by Ignite, give students a unique opportunity to build their confidence in engineering without feeling the need to pursue additional classes.

The findings from the Ignite Health program align with both constructivist and resilience theories. By creating a space for students to develop their own designs—from brainstorming to testing—

students were empowered to guide their own learning processes and ultimately become more confident STEM learners in the end. This experience also helped cultivate resilience across all participants, a trait that is necessary for success in the sciences in formal schooling and beyond.

Implications

These results suggest that informal engineering educational experiences such as Ignite's Health program have a positive impact on secondary school-aged children, particularly in increasing their engagement with and interest in the STEM field. This effect was especially pronounced among female and gender minority students, highlighting the potential for such programs to diversify participation in engineering and science-related disciplines. Given the positive impact of Ignite's programming, future studies should explore Ignite's longitudinal impact on returning students' education and career readiness/aspirations, furthering the program's long-term goal of empowering upward mobility across participants and mentors.

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